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The dynamics of social gaze: Visual attention and autonomic arousal among individuals with varying levels of autistic traits

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ABSTRACT

Accurate gaze detection is fundamental to social interactions and is impaired in individuals with higher levels of autistic traits. One mechanism is reduced attention to the eyes, but the reasons behind this atypical behavior remain debated. This study investigated whether reduced attention to the eyes associated with autistic traits stems from aversion or indifference. One hundred and twenty-seven adolescents and young adults with varying levels of autistic traits completed a gaze direction task while their eye position and pupil size were recorded. Higher levels of autistic traits were associated with reduced dwell time on the eye region after, but not before, gaze direction judgments, indicating reduced attention when it was not task-relevant. Autistic traits were associated with more frequent exits and re-entries from/to the eye region after judgments, indicating less stable social engagement. Additionally, autistic traits were not associated with enlarged pupillary responses, indicating no heightened arousal expected with aversion. These findings demonstrate reduced sustained engagement with the eyes among individuals with higher levels of autistic traits, consistent with indifference rather than aversion. The temporal specificity—emerging primarily after task completion—helps reconcile contradictory literature findings. Results suggest interventions should focus on enhancing sustained social engagement rather than addressing aversion.

1. Introduction

Gaze detection is a fundamental component of social cognition, serving as a crucial process that aids in inferring others' intentions and emotional states (Itier & Batty, 2009). The ability to attend to others' gaze is central to effective social interaction and plays a vital role in the development of social skills (Frischen et al., 2007). Many studies have reported that individuals with autism spectrum

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disorder (ASD) exhibit atypical looking behavior when attending to social stimuli, in particular faces, including reduced attention to the eye area, a pattern observed from childhood (Jones and Klin, 2013) and persisting throughout their lifetime (Pelphrey et al., 2002; Riby & Hancock, 2008). This atypical looking behavior has been associated with significant challenges, including impaired ability to communicate with others (Yoder et al., 2009), potentially contributing to social isolation. However, despite the significance of this phenomenon, its underlying mechanisms and even prevalence are still debated.

This alteration in gaze detection extends beyond diagnosed ASD, appearing also in individuals with higher levels of autistic traits who do not meet full diagnostic criteria (Chen & Yoon, 2011; Freeth et al., 2013; Hessels et al., 2018). This observation supports a dimensional conceptualization of autism, where social-communicative differences exist on a continuum across the population (Mandy et al., 2018). While most existing research has focused on clinical ASD samples, integrating findings from both clinical studies and the broader phenotype can provide a more comprehensive understanding of the mechanisms underlying atypical looking behavior.

1.1. Aversion Vs indifference

There has been substantial discussion on whether gaze avoidance in individuals with autism or with higher levels of autistic traits is due to aversion to social cues (Corden et al., 2008; Hutt & Ounsted, 1966; Moriuchi et al., 2017) or indifference towards them (Moriuchi et al., 2017). The aversion hypothesis suggests that gaze avoidance arises from negative emotions elicited by looking into others' eyes. In contrast, the indifference hypothesis suggests that individuals with autism are less responsive to the social significance of the eye area and less interested in the emotional reward derived from examining this region. Adjudicating between the aversion and indifference hypotheses is important both for theories of autism and development of interventions. If gaze avoidance stems from aversion, interventions would need to focus on down-regulating or managing negative associations or reactions to eyes—for example, through exposure or cognitive reappraisal techniques (Andréen et al., 2021). However, if gaze avoidance is linked to indifference, this suggests the need for interventions that enhance sustained social engagement while building on existing attentional capabilities (Wang et al., 2020).

Several studies have presented evidence supporting the aversion hypothesis, suggesting that this aversion manifests as physiological arousal or specific neural responses. Researchers have observed elevated skin conductance (Kylliäinen & Hietanen, 2006), and enhanced activation in fear-processing brain regions, such as the amygdala, during face-viewing in individuals with autism (Dalton et al., 2005; Tottenham et al., 2014). Pupillometry offers another effective method to measure physiological arousal. As an objective measure of autonomic nervous system activation, pupil diameter specifically reflects engagement of the sympathetic branch, providing a reliable indicator of physiological arousal during social interactions (Hess & Polt, 1960; Laeng et al., 2012). Using this technique, researchers have demonstrated increased pupil diameter in individuals with autism or autistic traits during face processing tasks (Harada et al., 2024; Kylliäinen & Hietanen, 2006; Lee et al., 2024; Reisinger et al., 2020; Wagner et al., 2013; Wagner et al., 2016). For example, Wagner et al. (2016) found that infant siblings of autistic children (who are at genetic high-risk for autism) with larger pupil sizes at 9 months showed lower social-communicative functioning at 18 months, suggesting that overarousal to social stimuli might lead to cascading difficulties in social development. Furthermore, Lee et al. (2024) found that autistic trait severity was associated with increased pupil dilation while judging mental states from the eye region across both ASD and typically developing participants. These findings collectively suggest that heightened autonomic arousal may contribute to gaze avoidance behavior in individuals with autism and higher levels of autistic traits, maybe as an attempt to reduce the excessive or uncomfortable physiological response (Cuve et al., 2018; Wagner et al., 2013). This response is characterized by **hyper**activation of the autonomic nervous system, potentially contributing to the observed alterations in social attention and interaction (Senju & Johnson, 2009).

Conversely, other researchers have found evidence supporting the indifference hypothesis. This hypothesis posits that individuals with autism may exhibit reduced engagement with social stimuli due to diminished perceived salience or reward value (Kampe et al., 2001). Evidence supporting this perspective includes reduced activation in early perceptual brain regions involved in social processing, such as the fusiform gyrus (Dalton et al., 2007) or the superior temporal sulcus (Pelphrey et al., 2005), suggesting diminished early engagement with social stimuli. Further evidence is provided by decreased pupil reactivity or pupil size when looking at social stimuli (Polzer et al., 2022; Sahuquillo-Leal et al., 2022; Segers et al., 2020) or decreased pupil diameter when viewing faces, particularly when fixating at the eye region (Nuske et al., 2015; Sepeta et al., 2012), suggesting low arousal or interest. Other studies have found a similar pattern of pupil constriction in individuals with higher levels of autistic traits (Hogan et al., 2022; Soker-Elimaliah et al., 2023; Wang et al., 2023; Zhao et al., 2022). Within this framework, atypical gaze behavior is associated with **hypo**activation of the autonomic nervous system and is conceptualized as passive avoidance of the eye area due to lack of interest. This perspective suggests that the observed differences in social attention may stem from reduced neural responsiveness to social stimuli rather than heightened aversive reactions.

The mixed findings regarding pupillary responses to social stimuli - with some studies reporting heightened reactivity and others documenting reduced responses - may be attributed to several methodological factors. First, studies employing emotionally-charged stimuli (e.g., angry or happy faces) tend to report enlarged pupillary response in ASD participants, likely because the stimuli elicit elevated arousal (Harada et al., 2024; Lee et al., 2024; Reisinger et al., 2020; Segers et al., 2020; Wagner et al., 2016). Second, studies using more challenging tasks tend to report heightened pupillary response in ASD, likely due to increased cognitive load (Falck-Ytter, 2008), as evidenced by prolonged reaction times (Frost-Karlsson et al., 2019; Miu et al., 2012; Nackaerts et al., 2012) and reduced accuracy (Wang et al., 2023). Overall, the preponderance of evidence seems to suggest reduced autonomic arousal in individuals with ASD or elevated autistic traits when viewing emotionally neutral face stimuli and employing a simple task.

1.2. The role of task demands

While the studies cited above generally reported reduced attention to eyes or active gaze avoidance in individuals with autism and with higher levels of autistic traits, others have failed to replicate these findings, instead observing patterns of visual exploration similar to those of neurotypical individuals (Bar-Haim et al., 2006; Evers et al., 2013; Fletcher & Frith, 2009; Georgescu et al., 2013; Rutherford & Towns, 2008; Van Der Geest et al., 2002). This inconsistency has led researchers to question whether gaze avoidance is a universal feature of autism and to explore potential explanatory factors (Riby & Hancock, 2009); see the reviews by Guillon et al. (2014) and Papagiannopoulou et al. (2014). Proposed explanations for these discrepancies include variations in stimulus type—e.g. static versus dynamic or real-life stimuli (Freeth et al., 2013; Papagiannopoulou et al., 2014; Speer et al., 2007; Riby & Hancock, 2009; Guillon et al., 2014; Von Dem Hagen & Bright, 2017), and differences in task demands across studies (Volkmar et al., 2004). In many studies reporting similar visual exploration patterns between ASD and neurotypical groups, participants' performance was recorded only in close temporal proximity of the stimulus appearance (as in the case of Bar-Haim et al., 2006) or participants were required to complete **post**-viewing evaluations (Fletcher & Frith, 2009; Papagiannopoulou et al., 2014; Rutherford & Towns, 2008; Van Der Geest et al., 2002, Evers et al., 2013, Georgescu et al., 2013). In contrast, studies documenting reduced attention to socially salient stimuli in ASD have predominantly utilized paradigms involving free-viewing (Cohen et al., 1989; Jones & Klin, 2013; Klin et al., 2002; Moriuchi et al., 2017; Riby & Hancock, 2008; see Xue et al., (2023) for a study with individuals with higher levels of autistic traits), or evaluation-based tasks that incorporate periods of unrestricted looking (Dalton et al., 2005), or extended stimulus presentations (Corden et al., 2008). This suggests that task demands and viewing conditions may drive at least some of the observed sustained attention to the eyes in individuals with ASD or higher levels of autistic traits.

1.3. The current study

To adjudicate between the aversion and indifference hypotheses, while addressing the inconsistencies in the literature regarding the prevalence of atypical looking behavior in individuals with autism or higher levels of autistic traits, we used an experimental paradigm that accounts for the potential confounds of emotional valence and task demands highlighted in previous research. Our design used static stimuli (photos of neutral faces, without emotional expression) and asks participants to make a judgment about the faces' gaze direction. Critically, we measured dwell times on the eye region both during task completion and in the subsequent free-viewing period. This setup enables us to separate task-driven attention from intrinsic social preference or aversion.

Distinguishing between active avoidance and passive indifference requires examining the dynamics of visual exploration, not just where individuals look and for how long. Active avoidance is reflected in systematic withdrawal behavior (actively moving away from the eye region and spending less time there than would be expected by chance). In contrast, passive indifference is characterized by random visual exploration patterns with no systematic preference for or against the eye region - neither approaching nor avoiding it more than would be expected by chance. Measuring both withdrawal and approach behaviors provides a comprehensive assessment of whether gaze patterns reflect purposeful avoidance or simply lack of social preference. Therefore, in this study we analyzed both the tendency to move away from the eyes (withdrawal; Kliemann et al., 2010; Lassalle et al., 2017) and the tendency to return to them (approach; Fletcher and Frith, 2009; Manyakov et al., 2018) during the gaze detection task to identify patterns consistent with active avoidance versus passive indifference.

Prior to the appearance of each face stimulus, participants were directed to look at a fixation cross located within the eye region of the upcoming face. This approach served two purposes: first, it ensures that any differences in task performance or eye movements during the task are not due to different starting gaze location; second, it verified that participants were attending to the screen when the face stimulus appeared. While initial fixation to the eyes may itself elicit heightened arousal and avoidance in studies using emotional faces (Stuart et al., 2023; Kliemann et al., 2012) or infant samples (Wang et al., 2025), this effect should be minimized in our adult sample viewing neutral expressions, enabling us to measure spontaneous gaze responses to the eye region under standardized viewing conditions.

Participants then completed the task, deciding whether they felt the face was looking at them or not. To measure spontaneous (non-task-driven) gaze withdrawal behavior, we examined the number of times participants' gaze exited the eye region after gaze direction judgments were completed. To capture spontaneous approach behavior, we examined the number of re-entries of gaze to the eye region after task completion. We also measured the average time participants looked at the eye region when re-engaging with it during free-viewing. We hypothesized that individuals with higher levels of autistic traits would exhibit reduced visual attention to the eye region, particularly after task completion—that is, during free-viewing periods following gaze direction judgments. Additionally, we expected these individuals to demonstrate decreased approach behavior toward the eye region during free-viewing.

To measure arousal as a proxy of aversion, we recorded participants' pupil diameter throughout the entire stimulus presentation interval (due to the inherent latency in pupillary reactions we did not distinguish between pre- and post- judgment periods see Bergamin & Kardon, 2003). Crucially, consistent with the preponderance of evidence in the literature, we hypothesized that less time looking at the eye region of a face would be accompanied by decreased autonomic arousal as indexed by pupillometry (Stefanelli et al., 2024). This pattern would align with theories of reduced social motivation and attenuated salience of social information in autism, rather than social anxiety or aversion (Moriuchi et al., 2017).

In this study we measured autistic traits as a continuous variable across all participants. As previously mentioned, research has shown that alterations in gaze detection also appear in individuals with higher levels of autistic traits who do not meet full diagnostic criteria (Chen & Yoon, 2011; Freeth et al., 2013; Hessels et al., 2018). Overall, the heterogeneity of the autistic phenotype points to the potential limitations of traditional categorical approaches (Anderson, 2008; Cuthbert, 2014; Cuthbert, 2020). This dimensional

approach may be particularly valuable for studying looking behavior, as it can capture subtle variations in social attention (Lombardo et al., 2019).

2. Methods

2.1. Participants

A total of 130 (92 female and 38 male) adolescents and young adults were recruited via early psychosis clinics, patient registries, social media campaigns, and community outreach in the Columbus, Ann Arbor and Detroit area. This sampling strategy aimed to capture individuals with a wide range of autistic traits and social functioning. Our sample included neurotypical individuals with no social dysfunction, individuals with subclinical autism traits and mild social dysfunction, and individuals with a clinical diagnosis of ASD (n = 23). Only participants who were diagnosed by a health professional qualified to diagnose ASD were included in this latter group. The varied sample allowed for a dimensional analysis across the full continuum of autistic features. The age range of 14–30 was chosen to examine a critical developmental period for social functioning, after the acquisition of eighth-grade language comprehension skills but before age-related cognitive decline. This window captures when social impairments often exert their greatest impact on life trajectories. All participants spoke English fluently and had normal or corrected-to-normal vision.

Exclusion criteria included active substance abuse within the past 30 days, IQ below 80, neurological or known Mendelian disorders. Three participants were excluded due to random or invariant response to the Gaze Detection Task. This left us with a sample of 127 participants (see Tables 1–2 for demographic and clinical information).

Participants (over 18 years old) or their parents (for participants under 18 years old) completed and signed the consent form for voluntary participation in the study. Participant assent was also acquired from children under the age of 18. The IRB at the University of Michigan approved our study (approval: HUM00174935) on February 25th, 2020. The IRB at The Ohio State University approved our study (approval: 2023H0055) on April 3rd, 2023.

2.2. Measures

Autism traits were assessed using three measures: (1) the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et al., 2012), an observational assessment administered by trained research staff; (2) the Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001), a 50-item self-report measure of autistic traits in adults (age 16 +); and (3) the Social Responsiveness Scale (SRS; Constantino & Gruber, 2012), a 65-item informant-rated measure of autism symptoms in real-world settings (see Supplemental Methods, Section 1.4.1, for full description of measures and administration procedures; see Table 2 for score distributions).

2.3. Eye gaze detection task

To examine looking behavior and physiological responses during social perception, we employed a gaze detection task adapted from Tso et al. (2012) and Lasagna et al. (2020) combined with eye tracking. This task allowed us to measure visual attention patterns and autonomic arousal both during active gaze discrimination and subsequent free-viewing periods.

Table 1
Participants' demographic characteristics.

Variable	N	Mean	SD	Min	Max
Age					
All	127	23.3	4.2	14.0	30.0
14-18	9	15.2	1.2	14.0	17.0
18-25	74	21.6	2.4	18.0	25.0
26-30	44	27.8	1.5	26.0	30.0
Race					
White	90	70.9 %			
Black or African American	7	5.5 %			
Asian	25	19.7 %			
More than one race	5	3.9 %			
Other/NR	0	0.0 %			
Sex (% Female)	127	71.7 %			
Ethnicity (% Non-Hispanic)	127	96.8 %			
Education (years)	127	15.4	2.8	8.0	23.0
Parental Education (years)	121	15.5	2.6	10.0	23.0
SES Score	127	2.5	0.9	1.0	5.0

Note. Sex was coded as female = 0, male = 1; SES = Socioeconomic Status (Self-Report based on the following guidelines – 1: Family of wealth, education, top-rank social prestige; 2: Professional or high level managerial position; adult should have attained college or advanced degrees; 3: Small businessperson, white collar and skilled workers, high school graduates; 4: Semi-skilled workers, laborers, education below secondary level; 5: Unskilled and semi-skilled workers, elementary education).

Table 2
Descriptive statistics of participants' autism trait measures and gaze detection task behavior.

Variable	N	Mean	SD	Min	Max
Autism Trait Measures					
AQ Total Score (self-report)	120	25.6	9.6	4.0	47.0
SRS Total Score (informant-rated)	103	56.5	33.7	2.0	147.0
ADOS-2 Communication	126	1.0	1.3	0.0	6.0
ADOS-2 Social Interaction	126	2.3	2.4	0.0	11.0
ADOS-2 Creativity / Imagination	126	0.1	0.4	0.0	2.0
ADOS-2 Stereotyped Interests / Restrictive Behaviors	125	0.9	1.3	0.0	6.0
Autism principal component	127	-0.0	1.0	-1.7	3.0
Gaze Perception Task Behavior					
Dwell time before decision (ms)	127	725.5	165.1	153.4	1137.2
Dwell time after decision (ms)	127	735.0	171.9	196.2	1147.1
Reaction time (ms)	127	1003.9	133.2	678.1	1330.2
Threshold (signal strength)	127	0.6	0.2	0.1	1.0
Width (signal strength)	127	1.0	0.4	0.3	2.4

Note: AQ =Autism Spectrum Quotient; SRS =Social Responsiveness Scale; ADOS-2 = Autism Diagnostic Observation Schedule, Second Edition.

2.3.1. Stimuli

The task stimuli included 108 naturalistic grayscale pictures of the frontal view of the faces of six actors (three males and three females) adapted from George et al. (2001). Each actor had 18 pictures, depicting 9 gaze angles ranging from 0º (direct eye contact) to 10º (averted eye contact), in 1.25º increments, and two possible orientations, left or right. In each picture, the face maintains a neutral, emotionless expression. Fig. 1 depicts example stimuli for one of the female actors. (see the Supplemental Methods, Sections 1.5.1 for additional details about stimuli presentation).

2.3.2. Task design

In this gaze detection paradigm, participants viewed a face in each trial (see Fig. 1c for stimulus timing). Participants were tasked with judging whether the faces were looking at them, or not, and could respond at any point during face presentation by pressing a button. The stimuli remained visible for the full 2000 ms, regardless of response timing. Since the mean reaction time was 1003.5 ms (SD= 133.6 ms), there was generally sufficient time left for free-viewing. The task contained 108 trials (12 presentations × 9 gaze angles). Stimulus presentation order was pseudorandomized to prevent consecutive presentation of the same actor with different gaze angles/orientations, which could create illusory motion and confound perception. This pseudorandomized sequence was held constant across participants. The combination of 108 trials, six different actors, and 18 unique gaze angle/orientation combinations provided sufficient trial-level variation to minimize systematic order effects. If the connection with the eye tracker was lost, or if the participant did not respond within the allotted two seconds, the trial was tagged as invalid and it was repeated.

Given the continuous nature of gaze direction, judgments of eye contact are subjective. Rather than accuracy, we quantified two perceptual metrics for each participant: the **threshold** and the **width**. The threshold reflects the observer's self-referential bias when judging eye contact, while width reflects the perceptual precision in discriminating between different gaze angles. Since gaze angles were converted to an "eye-contact signal strength" scale of 0–1, with 0 corresponding to averted gaze at 10° and 1 direct gaze at 0°, to enable psychometric fitting on a standardized perceptual scale, threshold and width are presented in units of "eye-contact signal strength," such that lower thresholds indicate stronger self-referential bias and lower width indicate higher perceptual precision. Additional details for deriving these metrics are provided in the Supplemental Methods, Section 1.3 and Figure S1.

2.4. Eye tracking data

2.4.1. Eye movement data

Eye movement data were collected using an EyeLink 1000 eye tracker (SR Research) with a sampling rate of 500 Hz for monocular tracking of each participant's dominant eye. Calibration was performed using a 13-point grid with experimenter-controlled advancement between targets and randomized target order. Fixations and saccades were identified using the EyeLink 1000 SR's online parser with standard cognitive research thresholds: velocity threshold of 30°/s, acceleration threshold of 8000°/s^2, and motion threshold of 0.15°. Eye movements exceeding these thresholds were classified as saccades, while periods between saccades with stable gaze position were classified as fixations. Blinks were identified as periods of missing or distorted pupil data (additional details on the eye tracker setup are provided in the Supplemental Methods, Section 1.1).

Three primary dependent variables were derived from the eye-tracking data. Task-related visual attention to the eye region was operationalized as the total dwell time (in milliseconds) on the eye area of interest (AOI) before participants made their gaze direction judgment via button press (see the Supplemental Methods, Section 1.5.1 and Figure S3 for additional details about AOI definition; see Section 1.5.2 and Table S2 for additional details about eye-tracking data preprocessing, including definition and descriptive statistics of fixations and saccades). Post-task visual attention to the eye region was defined as the total dwell time on the eye region after the judgment until stimulus offset. Approach behavior was quantified as the number of gaze re-entries to the eye region following the initial judgment, where a re-entry was defined as any fixation in the eye region following a fixation outside this region. Gaze re-entries were operationalized as gaze point location transitions into the eye AOI following a prior exit. We used this approach because our

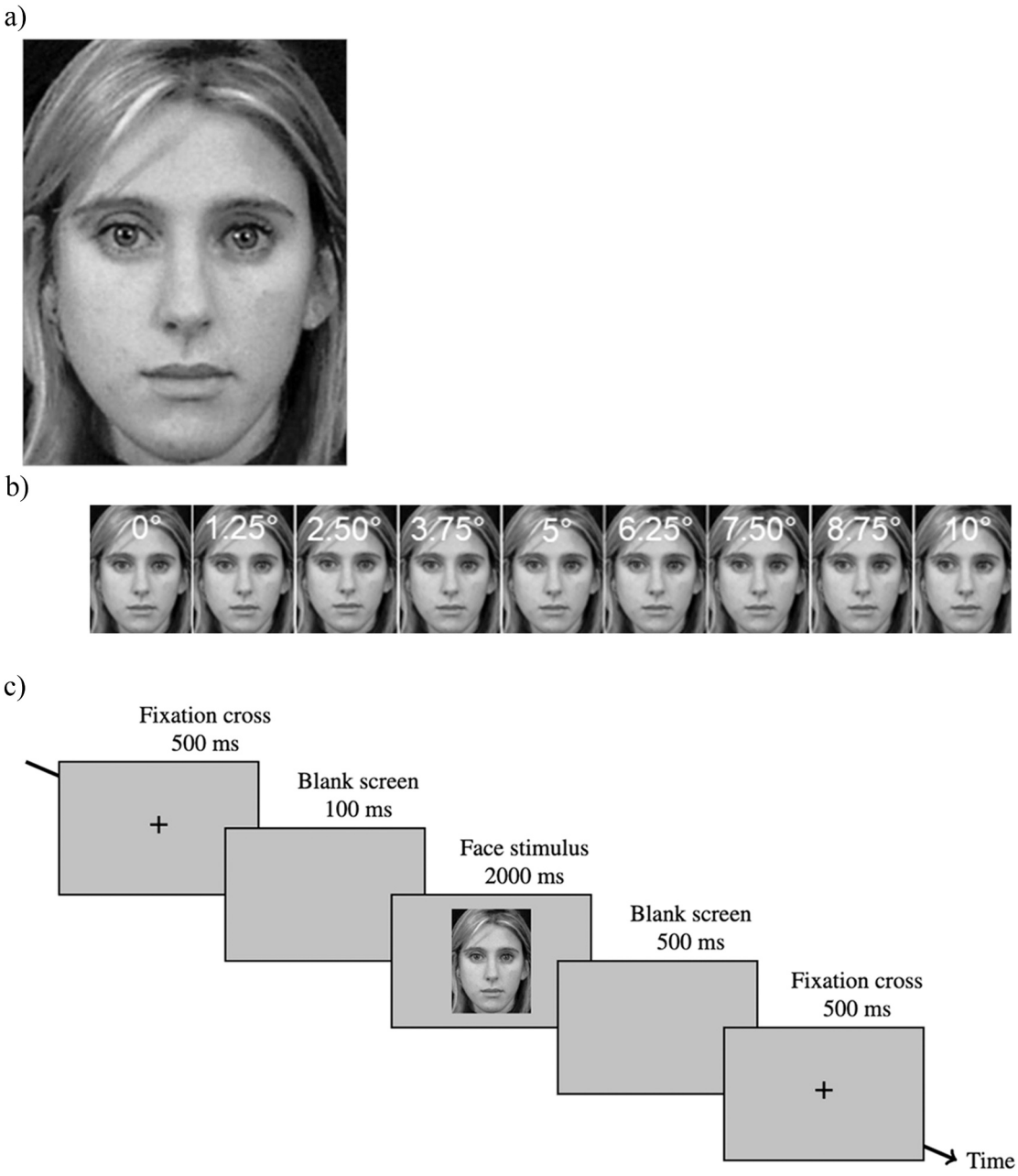

Fig. 1. Gaze detection task stimuli. a) A stimulus example, with the gaze directed at the participant (gaze angle of 0º). b) Face stimuli had 9 gaze angles, ranging from 0º (Direct eye contact) to 10º (Averted eye contact) in 1.25º increments. c) Task stimulus timing.

primary measure—dwell time within the eye AOI— was computed from the cumulative duration of all gaze point locations falling within the AOI boundary. Using the same approach for exit/re-entry counts ensures methodological consistency between our temporal (dwell time) and frequency (exits/re-entries) metrics. This approach allows us to measure more general gaze instability around the eye region, without relying solely on saccade event detection. In addition, the eye AOI represents an analytical boundary rather than a physical feature that would necessarily trigger saccadic movements, and the limited time available after the decision only allows for a very limited number of saccades to be performed.

2.4.2. Pupillometry data

The fourth primary dependent variable, pupil size, was used to index physiological arousal. It was recorded at 500 Hz sampling rate (concurrent with eye position data) throughout each trial. To determine the pupil's area and center position, the system implements the Centroid Model (see the Supplemental Methods, Section 1.2, for additional details about pupil data collection and processing). Because

the EyeLink 1000 SR reports pupil size in arbitrary units (AU) that vary with subject setup and are not directly comparable between participants, we recalculated pupil dilation using percent change from baseline to ensure between-subject comparability.

3. Statistical analyses

Statistical analyses were conducted using R (version 2023.12.1). To better conceptualize the diverse array of autism traits a principal component analysis (PCA) was conducted to derive a single composite score (represented by the first principal component, explaining 44.3 % of variance) for autistic traits using ADOS subscores, AQ, and SRS scores as input variables (see Table S1). Detailed methodology is provided in the Supplemental Methods, Section 1.4.2. Detailed inter-correlations between individual autistic traits measures, the composite score that we derived, and gaze task behavior variables are reported in Supplemental Results, Section 2.1 and Table S3. While individual autism trait measures showed mostly weak or non-significant correlations with gaze task variables, the composite score was significantly associated with perceptual width (in terms of poorer precision in discriminating between different gaze angles) and with reduced attention to the eyes after task completion. This shows that our composite measure effectively captures heterogeneous aspects of autistic traits that individually contribute to different visual attention patterns.

To examine relationships between autistic traits and visual attention patterns, we conducted multiple regression analyses with dwell times in the eye region as dependent variable. Since each image was presented for a fixed duration of 2 s, participants who took longer to make their judgment had less time available to look at the image afterwards. Therefore, reaction time was included as a covariate in all analyses to account for these differences in available viewing time. In addition, we repeated the main analyses using proportional dwell times before and after the decisions. For the pre-decision period, proportional dwell time was computed as the percentage of time between stimulus onset and decision spent looking at the eyes. For the post-decision period, it was calculated as the percentage of time between decision and end of trial spent looking at the eyes. Because the results were essentially the same, these are presented in the Supplemental Results (Sections 2.2 and 2.3, Figures S4, S5, S6.) Given that our sample included 23 participants with a clinical ASD diagnosis, we also conducted supplementary analyses comparing participants with and without a diagnosis to examine whether the pattern of results was consistent within the clinical subgroup or driven primarily by subclinical traits. Because the pattern of results remained consistent with our primary dimensional analyses, these group comparisons are presented in the Supplemental Results (Section 2.3, Figures S5, S6).

To examine relationships between autistic traits and the number of exits from the eye region and re-entries to the same area after task completion, we conducted negative binomial regressions, always controlling for reaction times. For pupillary analyses, we used linear regression to test the relationship between autistic traits and baseline-corrected pupil size. The combination of these measures provides insight into participants' social attention patterns in terms of approach vs. avoidance tendencies. Both unstandardized (*b*) with 95 % confidence intervals and standardized (β) regression coefficients are reported to facilitate interpretation of effect sizes. For negative binomial models, Incidence Rate Ratios (IRR) are reported as measures of standardized effect size, representing the change in outcome for one standard deviation increase in the predictor. All analyses were conducted at $\alpha = .05$.

A null finding regarding the relationship between autistic traits and baseline-corrected pupil size would be consistent with the

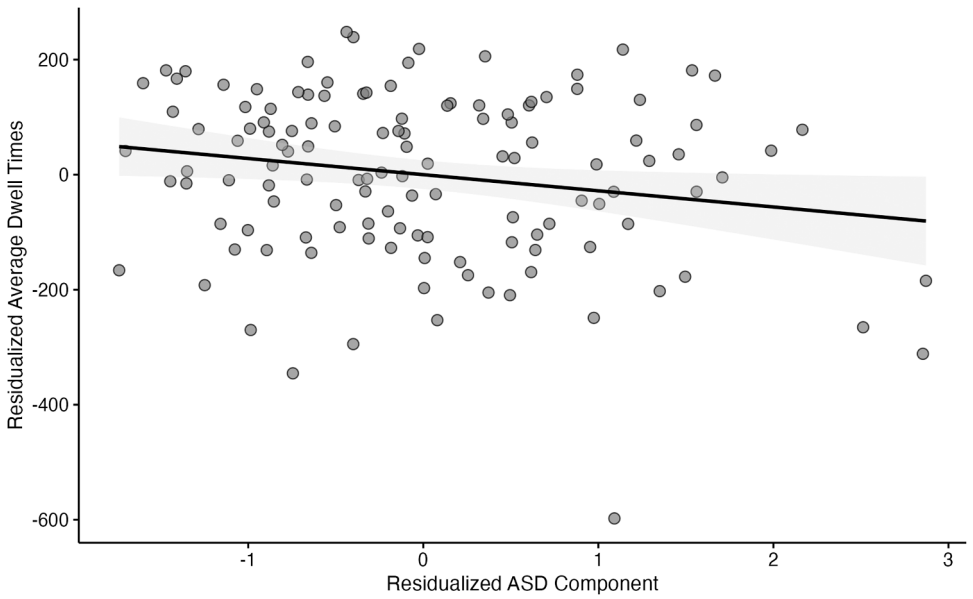

Fig. 2. Post-judgment dwell times as a function of autistic traits. The x-axis represents the residualized ASD component score (after controlling for reaction times), with higher values indicating more severe autistic traits. The y-axis shows the residualized average dwell times in milliseconds. The line indicates the linear regression fit, demonstrating a negative association between ASD traits and post-judgment eye area dwell times ($b = -29.51$, 95 % CI [-55.16, −3.87], $\beta = -0.17$, $p = .024$).

hypothesis that autistic traits are not associated with heightened arousal when viewing faces. However, given that traditional null hypothesis significance testing cannot provide evidence for the absence of an effect, we conducted Bayesian analysis to quantify the strength of evidence for or against this relationship. We used the lmBF function from the BayesFactor package in R to compute Bayes Factors (BF) comparing a model with autistic traits as a predictor of baseline-corrected pupil size (alternative model) against an intercept-only null model (Morey et al., 2015). BF provides information regarding the relative strength of evidence of the alternative vs. null model, with values > 1 indicating support for the alternative model and values < 1 indicating support for the null. Following conventional interpretation guidelines (Jeffrey, 1961) of strength of evidence, BF between 1–3 provides "anecdotal" evidence for the alternative model, 3–10 "substantial" evidence, 10–30 "strong" evidence, 30–100 "very strong" evidence, and > 100 "decisive" evidence. Similarly, BF between 0.33 and 1 provides "anecdotal" evidence for the null model, 0.10 and 0.33 "substantial" evidence, 0.033 and 0.10 "strong" evidence, 0.01 and 0.033 "very strong" evidence, and < 0.01 "decisive" evidence.

4. Results

To test whether individuals with higher levels of autistic traits showed increased avoidance after completing the task, we examined the relationship between autistic traits and dwell time on the eye region, both before and after task completion, while controlling for reaction times. This relationship was not significant before task completion ($b = -15.85$, 95 % CI [-36.41, 4.70], $\beta = -0.10$, $p = .130$), but became significant after task completion ($b = -29.51$, 95 % CI [-55.16, −3.87], $\beta = -0.17$, $p = .024$), suggesting increased social avoidance among those with higher levels of autistic traits when it is not task-relevant (see Fig. 2).

To examine the relationship between autistic traits and the number of exits from and re-entries into the eye region after task completion, we conducted negative binomial regressions, controlling for reaction time. The results showed that autistic traits significantly predicted more frequent exits ($b = 0.050$, 95 % CI [0.033, 0.067], IRR = 1.052, $p < .001$) and re-entries ($b = 0.039$, 95 % CI [0.019, 0.058], IRR = 1.039, $p < .001$). This suggests that individuals with higher levels of autistic traits demonstrated more frequent approach and withdrawal looking behavior during free-viewing. Additionally, autistic traits significantly predicted shorter dwell times per re-entry after task completion ($b = -20.76$, 95 % CI [-39.99, −1.53], $\beta = -0.18$, $p = .035$), suggesting a succession of brief engagements with the socially salient eye region. Finally, autistic traits showed no significant relationship with percent change in pupil size over the baseline (b = −0.36, 95 % CI [-0.96, 0.23], $\beta = -0.11$, p = .232), which is inconsistent with the notion of increased arousal due to aversion. To provide positive evidence for the absence of a relationship between autistic traits and pupil size, we conducted a Bayesian linear regression. The analysis yielded a Bayes Factor (BF) of 0.36, providing anecdotal evidence in favor of the null hypothesis. This indicates that the data are approximately 2.75 times more likely under the null model (no relationship between autistic traits and pupil-indexed arousal) than under the alternative model (relationship exists). This finding supports our interpretation that reduced eye contact in individuals with higher autistic traits is not driven by heightened physiological arousal.

5. Discussion

The overall purpose of the current study was to address the inconsistencies in previous research investigating looking behavior and autonomic arousal during face-viewing in relation to autistic traits. We employed a gaze detection task combined with gaze location and pupil size measures, and dimensional assessments of autistic traits, to examine the mechanisms underlying atypical looking behavior during face observation in individuals with varying levels of autistic traits. Our primary aim was to compare the aversion versus indifference hypotheses as potential explanations for any observed atypical looking behavior.

5.1. Gaze avoidance and task demands

The first focus of our research was to examine whether gaze avoidance is consistently present across different task demands by examining how visual attention to eyes varies between periods of active task completion versus free-viewing. We anticipated that individuals with higher levels of autistic traits would show reduced attention to the eyes and that this reduction would be more pronounced during periods when attention to the eyes was not required for task performance. Consistent with these predictions, higher levels of autistic traits were associated with reduced time spent looking at the eye region, but only in the period after gaze direction judgments had been made. This temporal specificity in the relationship between autistic traits and visual attention to the eyes highlights the crucial role of task demand, and helps reconcile seemingly contradictory findings in previous literature, where some studies reported gaze avoidance (Klin et al., 2002; Moriuchi et al., 2017; Pelphrey et al., 2002) while others did not (Fletcher-Watson et al., 2009; Georgescu et al., 2013; Rutherford & Towns, 2008).

Studies reporting typical gaze patterns in autism often required evaluation tasks to be completed after the stimuli observation was completed, demanding sustained attention throughout the viewing period (Fletcher-Watson et al., 2009; Georgescu et al., 2013; Rutherford & Towns, 2008). The current findings suggest that individuals with higher autistic traits can maintain typical gaze patterns when task demands require it but may show different underlying processing or diverge when such demands are removed. In contrast, studies documenting reduced attention to eyes typically employed free-viewing paradigms (Klin et al., 2002) or included periods of unrestricted looking (Dalton et al., 2005). Our results help reconcile these findings by demonstrating that looking behavior varies as a function of task demands, consistent with proposals that individuals with autism initially orient to eyes but disengage when it no longer has extrinsic value or relevance (Bar-Haim et al., 2006; Ristic et al., 2005). This task-dependent variation suggests that individuals with higher levels of autistic traits may show reduced spontaneous re-evaluation of social judgments, potentially reflecting decreased intrinsic interest in social feedback (Chevallier et al., 2012). Consequently, studies investigating attention to the eye region of faces

only when this region contains task-relevant information may underestimate social attention deficits in autism, while those focused solely on free-viewing may overstate them.

5.2. Aversion Vs indifference

As expected, we did not find evidence of reduced peak pupil dilation with increasing autistic traits. Together with the findings of reduced sustained attention but frequent brief re-engagements with the eye region, our results do not support the aversion hypothesis, which would predict heightened autonomic arousal in response to social stimuli and less re-engagements. While the absence of heightened pupillary responses might suggest indifference towards social stimuli in individuals with higher levels of autistic traits (Martineau et al., 2011; Nuske et al., 2015), our behavioral findings suggest a more complex picture than mere indifference. After completing the gaze judgment task, individuals with higher levels of autistic traits showed a distinctive pattern: they repeatedly moved away from and then back to the eye region, but these returns were brief. Specifically, while higher levels of autistic traits predicted both exits from and re-entries to the eye region after task completion, the relationship with exits was notably stronger, and the dwell times during re-entries were shorter. This pattern of frequent sampling with reduced sustained engagement suggests that individuals with higher levels of autistic traits maintain awareness of social information while modulating their exposure to it (Elsabbagh et al., 2013). Thus, rather than either pure aversion or simple indifference, we observe what appears to be an active regulatory strategy. Kylliäinen and Hietanen (2006) found that while individuals with autism showed overall lower arousal levels, direct gaze specifically triggered stronger physiological responses compared to averted gaze. This suggests that individuals with higher levels of autistic traits may develop a compensatory strategy - maintaining brief but repeated eye contact rather than sustained attention - to gather social information while preventing potential overarousal (Markram & Markram, 2010). This interpretation aligns with longstanding proposals that reduced eye contact in autism may serve to regulate physiological arousal (Hutt & Ounsted, 1966) while still allowing for social information processing. However, we cannot rule out that the pattern of decreased engagement and increased re-entries during periods without task demands reflects a more general difficulty sustaining attention, rather than a regulatory strategy. This interpretation would suggest that individuals with higher levels of autistic traits experience challenges maintaining focused attention when external task constraints are removed, regardless of stimulus type. Future research should directly test whether this pattern is unique to social stimuli or extends to non-social stimuli as well.

These findings must be considered in the broader context of pupillary response research in autism, which is complicated by substantial heterogeneity across studies and individuals (Bleimeister et al., 2024; Stefanelli et al., 2024). While our and several other studies report reduced or unchanged pupillary responses to social stimuli, some research has found increased autonomic arousal. The variability in pupillary responses may relate to differences in participants' developmental level (Hepach et al., 2020), in the stimuli's emotional content (Harada et al., 2024; Lee et al., 2024; Reisinger et al., 2020; Segers et al., 2020; Wagner et al., 2016), or in task demands (Frost-Karlsson et al., 2019; Falck-Ytter, 2008). These apparently contradictory results may also reflect genuine intra-individual heterogeneity in how individuals with autism process social information. Recent evidence from Bleimeister et al. (2024) demonstrates that children with autism show significantly weaker intra-subject correlations in pupil size while watching naturalistic social interactions, suggesting less consistent or synchronized autonomic responses to social information. This reduced synchronization was independent of differences in gaze patterns and was particularly pronounced during complex social scenes. Taken together, the mixed findings in the literature highlights the importance of considering factors such as stimulus characteristics, task demands, developmental level, and individual differences when interpreting pupillary responses in autism research.

5.3. Social implications and therapeutic interventions

Diminished attention to the eyes during social interactions has significant implications. In participants with higher levels of autistic traits, reduced eye contact may impair detection of emotional cues (Poljac et al., 2013) and interpretation of mental states (Morgan et al., 2023). These atypical attentional patterns can cascade into broader challenges with social functioning (Riddiford et al., 2022). Our findings have important implications for understanding and treating atypical looking behavior. The temporal specificity of reduced attention to the eye region - emerging primarily after task completion - suggests that interventions need to focus not only on establishing basic eye contact skills but also on maintaining social engagement. While individuals with higher levels of autistic traits can effectively modulate their looking behavior when explicitly required by task demands, they show difficulty maintaining sustained social attention once these demands are removed. But this pattern also indicates preserved capacity for social attention that could be leveraged in treatment (Hustyi et al., 2023).

Our results suggest that interventions may benefit from a gradual approach. Initial training could focus on establishing task-based eye contact, where clear expectations promote engagement, as demonstrated in studies using discrete trial instruction and prompting procedures (Bagaiolo et al., 2017; Carbone et al., 2013; Cook et al., 2017). One promising approach to facilitate this is gaze-contingent adaptive cueing therapy, where real-time eye-tracking is used to provide immediate feedback and gradually suppress supportive cues as performance improves (Q. Wang et al., 2020; Sosnowski et al., 2022). This intervention dynamically adjusts to individual performance while maintaining naturalistic viewing conditions, offering a bridge between a more structured approach and more spontaneous social attention. The finding that participants with higher levels of autistic traits showed more frequent but briefer re-entries to the eye region after task completion suggests they may already employ compensatory strategies - maintaining social monitoring while modulating its intensity - a pattern that demonstrates a measure of behavioral flexibility that could facilitate interventions. Additionally, our finding that individuals with higher levels of autistic traits can modulate their social attention based on task demands suggests that these individuals can engage in sustained eye contact when they perceive clear extrinsic value in doing so. Thus,

interventions could incorporate explicit coaching about the practical and social benefits of maintaining attention to others' eyes during natural interactions.

6. Limitations

A limitation of our study is the demographic distribution in our sample. Our participant pool skewed heavily female (71.7 %), highly educated, with White participants comprising the majority (70.9 %, n = 90). Future studies with samples of demographic composition closer to that of the general public are warranted to evaluate the generalizability of the findings. In addition, future studies would benefit from using more ethnically diverse facial stimuli to enhance generalizability and examine whether gaze patterns vary across different face types. Another limitation of our study is the scarcity of participants at the severe end of the autism trait spectrum, although the distributions of the autism-related measures generally approximated normal and were consistent with our dimensional conceptualization of autism traits. Replicating the findings in clinical ASD samples of varying levels of functioning would further affirm the translational value of these findings.

7. Conclusion

In conclusion, our findings showed evidence of atypical looking behavior in individuals with higher levels of autistic traits. While these individuals showed reduced attention to eyes particularly after completing task-relevant judgments, they did not exhibit heightened physiological arousal that would suggest active aversion to social stimuli. These results suggest that indifference is a more likely explanation than aversion, and the pattern of frequent but brief re-engagements suggests a compensatory mechanism that allows for social information gathering while potentially preventing overarousal. The observed differences in looking behavior before and after explicit judgments underscore the importance of considering task structure when interpreting social attention patterns in autism.

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Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ivy Tso reports financial support was provided by National Institute of Mental Health. Costanza Colombi reports financial support was provided by RC grant, Italian Ministry of Health. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.reia.2026.202821.

Data availability

Data will be made available on request.

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